N84 25079

THE DESIGN AND DEVELOPMENT OF A RELEASE MECHANISM FOR SPACE SHUTTLE LIFE-SCIENCE EXPERIMENTS

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ABSTRACT

This paper describes the design, the development, and the testing of a release mechanism for use in two Life Science Experiments on the Spacelab 1, 4, and D1 missions. The mechanism is a self-latching ball-lock device actuated by a linear solenoid. An unusual feature is the tapering of the ball-lock plunger to give it a near-constant breakout force for release under a wide range of loads. The selection of the design, based on the design requirements, is discussed. A number of problems occurred during development and test, including problems caused by human factors that became apparent after initial delivery for crew-training sessions. These problems and their solutions are described to assist in the design and testing of similar mechanisms.

INTRODUCTION

The Spacelab Vestibular Experiments are designed to investigate changes in vestibular functions during weightless conditions and space motion sickness.

The Otolith Spinal Reflex or "Hop and Drop" Experiment tests the effects of alterations in Otolith organ contributions to leg muscle activity in specific experimental situations, each involving a different motion of the subject. Hopping and unexpected fall tests will be conducted on-orbit in Spacelab and on the ground before and after flight. The on-orbit tests employ elastic cords to provide the forces necessary to keep the subject in place while hopping, or to propel him towards the floor in the falls.

In the fall test section of the Otolith Spinal Reflex Experiment it is necessary to release the subject without warning, so that he will accelerate towards the floor under the influence of the extended cord assemblies. The release mechanism used in this test incorporates some unique design features and is the subject of this paper.

The fall test configuration on Spacelab 1 is shown in Figure 1.

REQUIREMENTS

- Function: sudden and smooth release of subject without audible or visible warning under a wide range of loads and voltages (0 to 100 Kg, 19 to 32 V)

- Release Delay: not to exceed 0.1 second from command until subject starts to fall and to be very consistent for a given load and voltage

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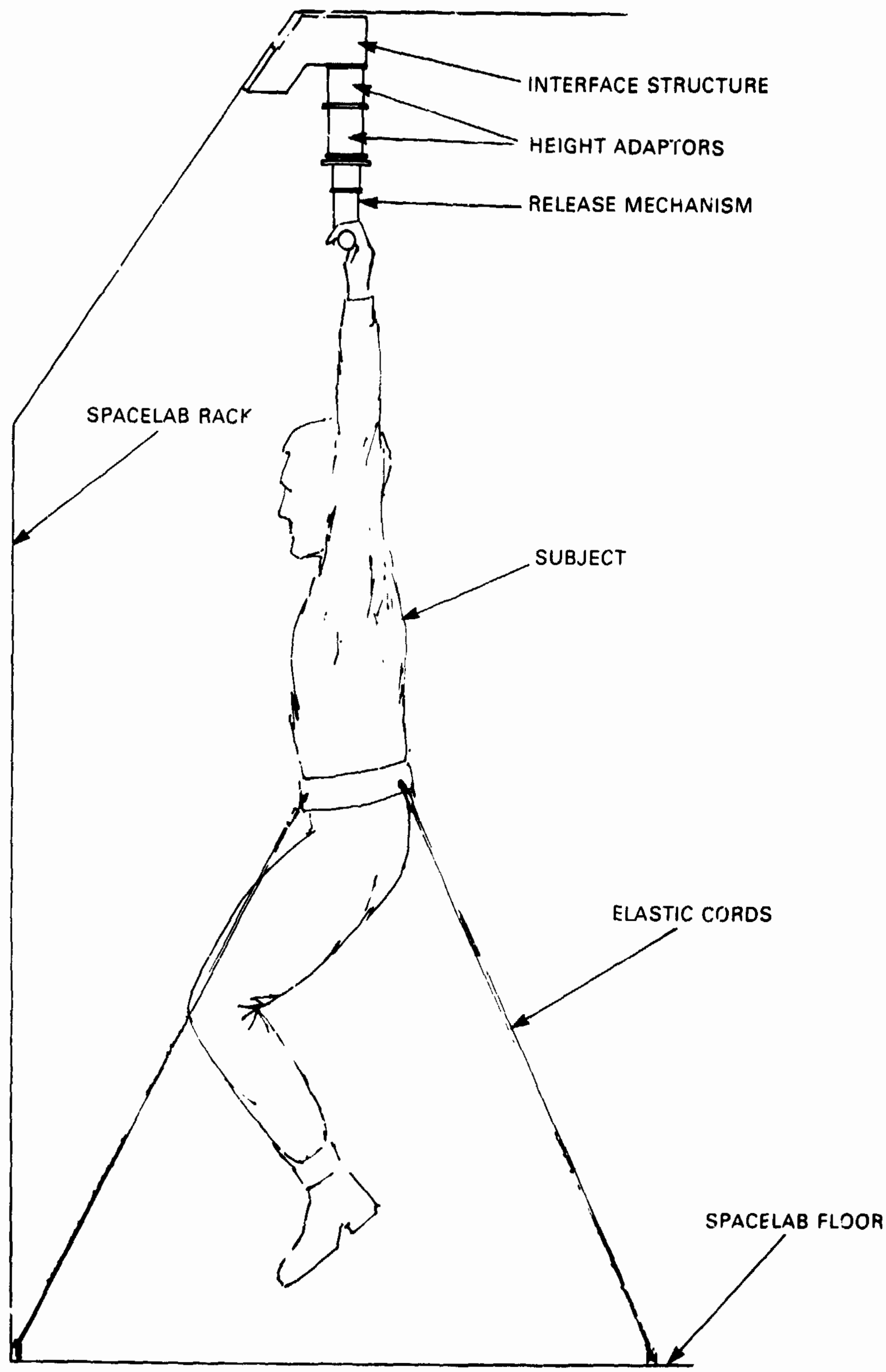

Figure 1. Fall Test Configuration

- To be self latching in the retention position
- Low weight (2.5 Kg), size, and power consumption (40 W at 24 V)
- To be reusable immediately after each release
- No stored energy devices that could impact crew safety
- Lifetime: 1,500 release cycles under a specified load profile, before refurbishment

DESIGN

Various design approaches were initially considered. The main problem was to achieve release under high external load within the mass, power, time and safety constraints.

Pyrotechnic and pneumatic devices offer the best force/weight ratio but would violate the reusability and safety requirements for the Spacelab interior.

The release delay of a linear actuator employing an electric motor with reduction gearing and a lead screw was found to be excessive and the subject would obtain an audible advanced warning of the release.

It was eventually determined that a solenoid-actuated ball-lock mechanism would meet the performance and safety requirements and would provide a compact, low-power design, with a low number of moving parts.

The active part of the release mechanism is a handlebar providing a two-handed grip and carrying a solenoid-actuated ball-lock pin vertically mounted at its center point. The mating part is an outer sleeve with a semi-circular cross-section groove that is attached to the Spacelab structure.

On latch-up, the three balls are radially locked into the groove in the fixed outer sleeve and the load imparted by the subject under the influence of the extended cord assemblies is taken by the balls in shear. The plunger is held in the extended position by a compression coil spring. When energized, the solenoid withdraws a plunger and permits the balls to collapse toward the pin centre and out of the groove, which allows the ball lock pin to slide out of the outer sleeve under the influence of the axial load.

A large solenoid force, however, was predicted for release under high load because of high friction on the plunger caused by the clamping action of the balls. In addition, the release characteristics of the mechanism would vary considerably as a function of load. This problem was solved by using a tapered plunger with a half-cone angle equal to the arctangent of the predicted coefficient of friction. The plunger which was neutral under load, needed only a small force to release.

The principle is illustrated in Figure 2.

The flight-standard release mechanism is shown in Figure 3.

A development model was manufactured and tested using a spring gage instead of a solenoid so that the release forces could be measured under a wide range of loads. A series of plungers with various taper angles were tested and an optimum angle selected.

The theoretical and measured plunger release forces are shown in Figure 4 and Figure 5 for various loads and plunger taper angles.

The solenoid used for the release mechanism involved modification of a standard bought out unit for two reasons:

1. Replacement of unacceptable materials with those approved by NASA for manned spaceflight applications

2. Performance improvement (particularly the force capability at the fully-extended position)

The performance before and after modification is shown in Figure 6.

DEVELOPMENT PROBLEMS AND SOLUTIONS

Design modification resulted from development testing in three areas:

- Release characteristics
- Retention characteristics
- Lubrication life

The following paragraphs describe these areas.

Release Characteristics

The unit exhibited occasional failure to release when the solenoid was energized because of:

- Insufficient solenoid force
- Excessive retention spring force
- Lubricant failure
- Unexpected mechanism kinematics

Investigation of the first three items resulted in minor improvements but the problem was not completely solved.

A thorough review of the mechanism design was then conducted and a potential jamming mode of the mechanism was predicted by analysis. This mode involved the latch-up kinematics of the mechanism as shown in Figure 7.

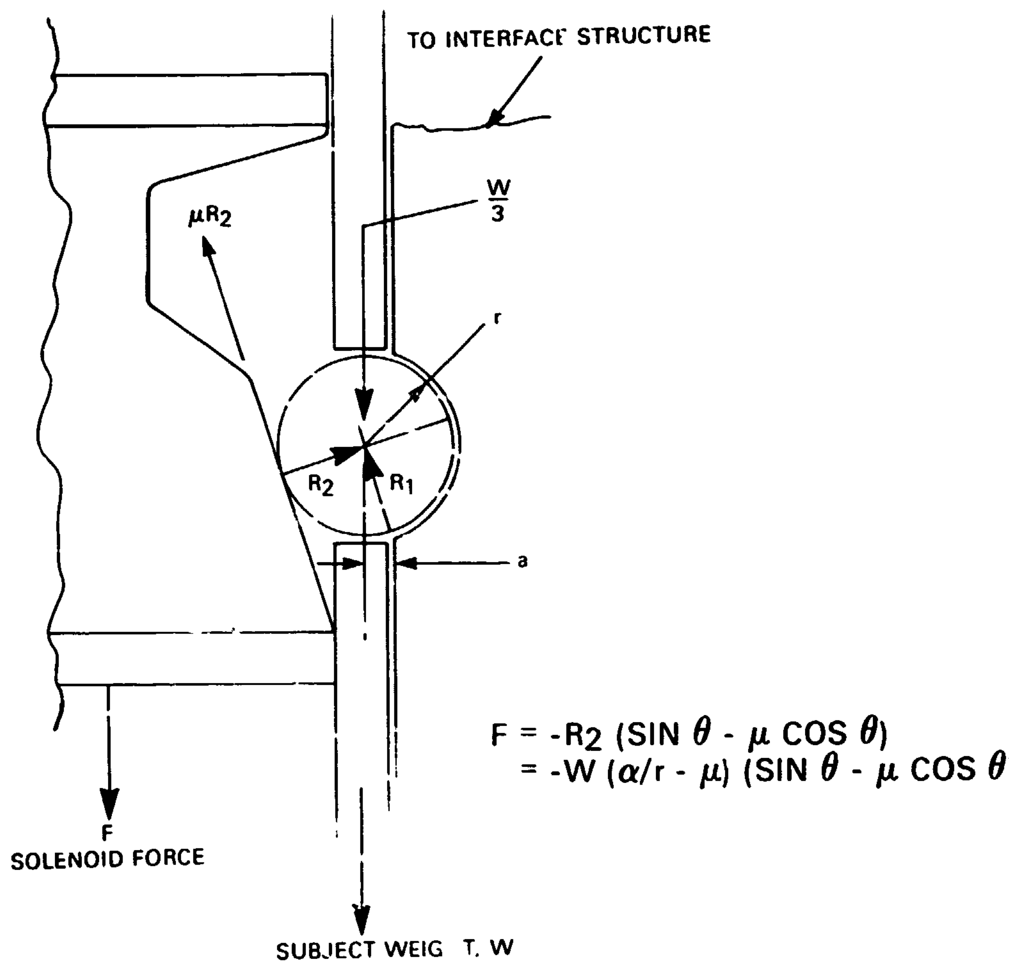

Figure 2. Principle of Release Mechanism

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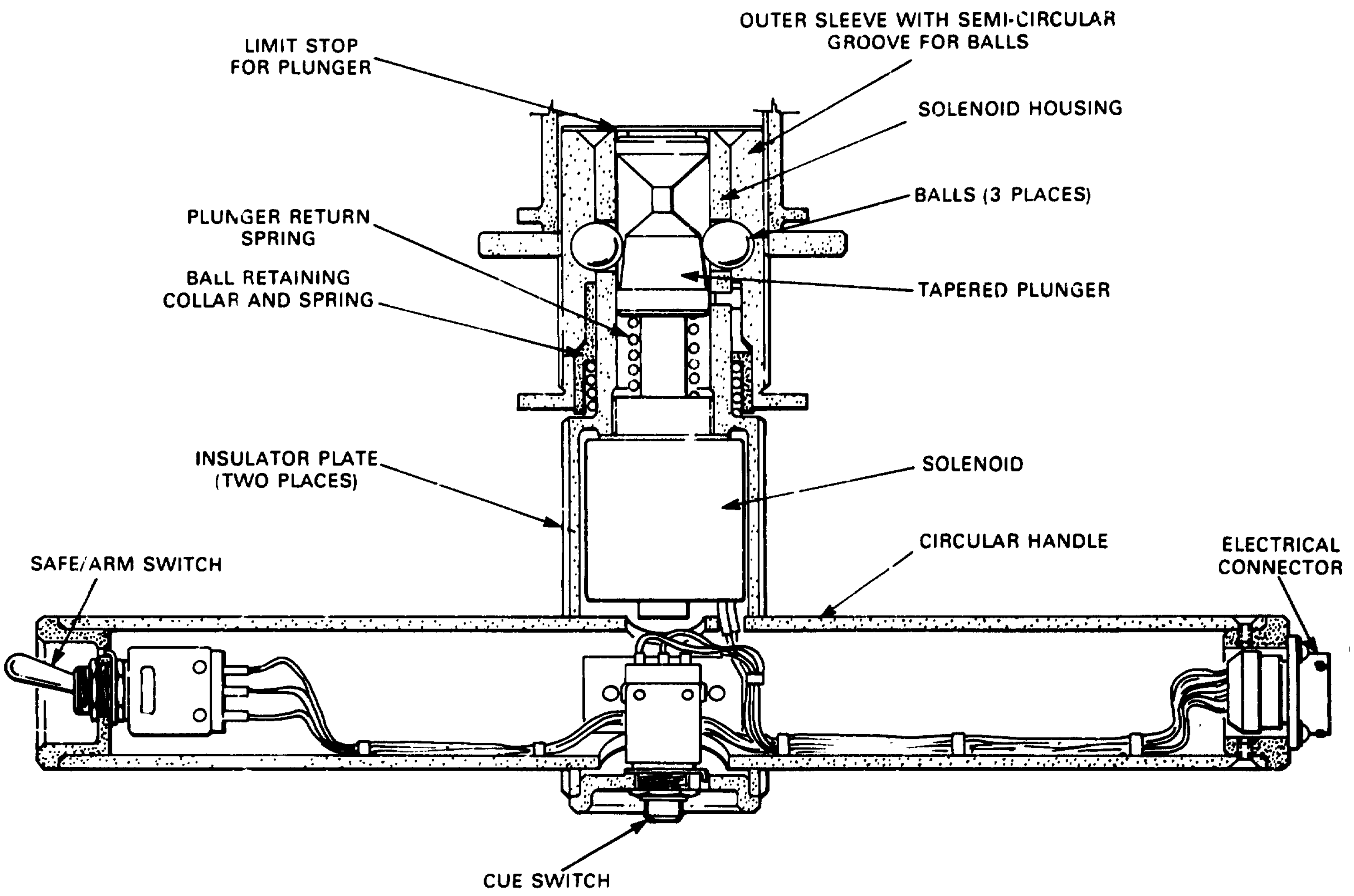

Figure 3. Release Mechanism Flight Unit

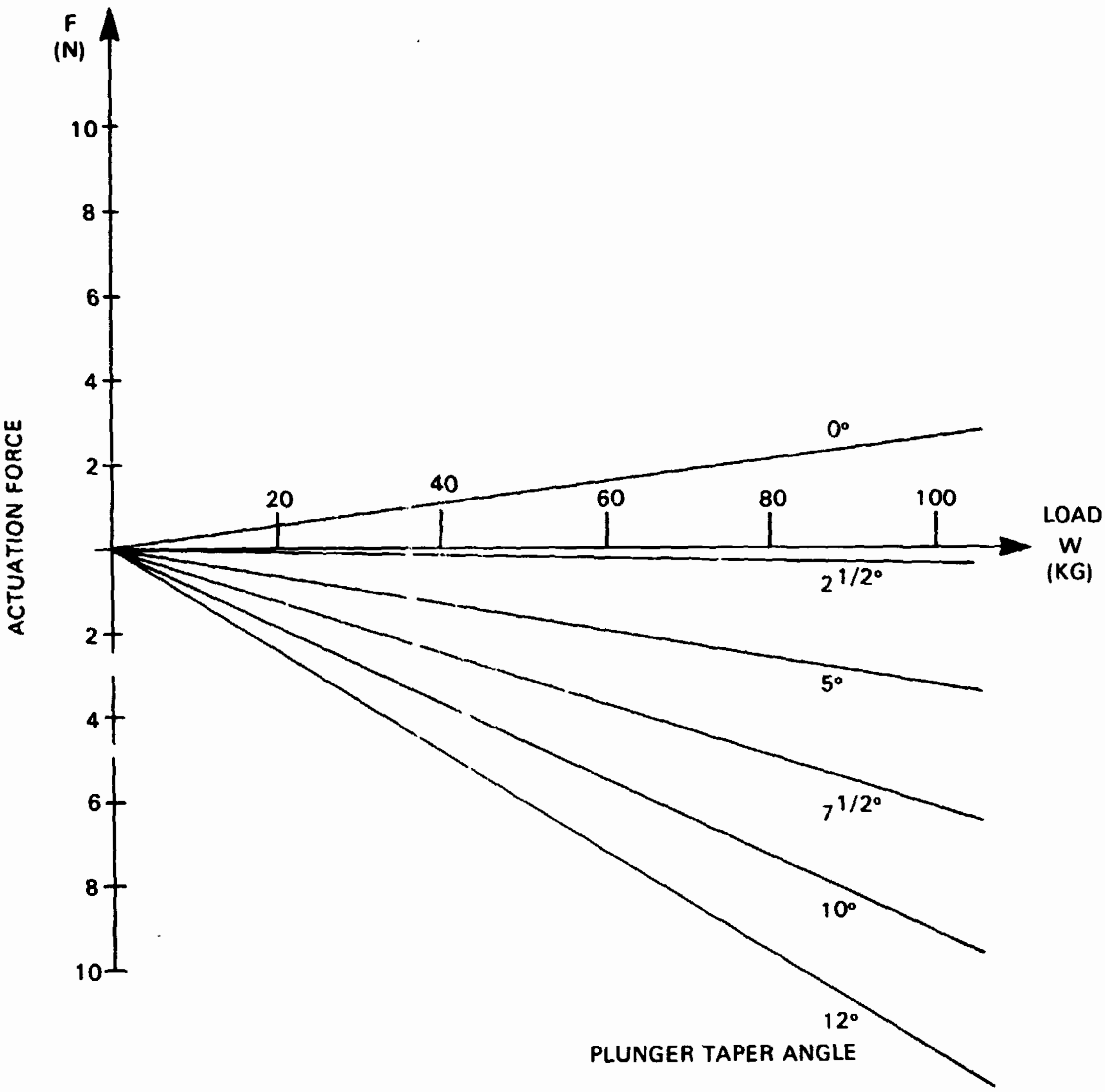

Figure 4. Theoretical Pe:formance of Release Mechanism

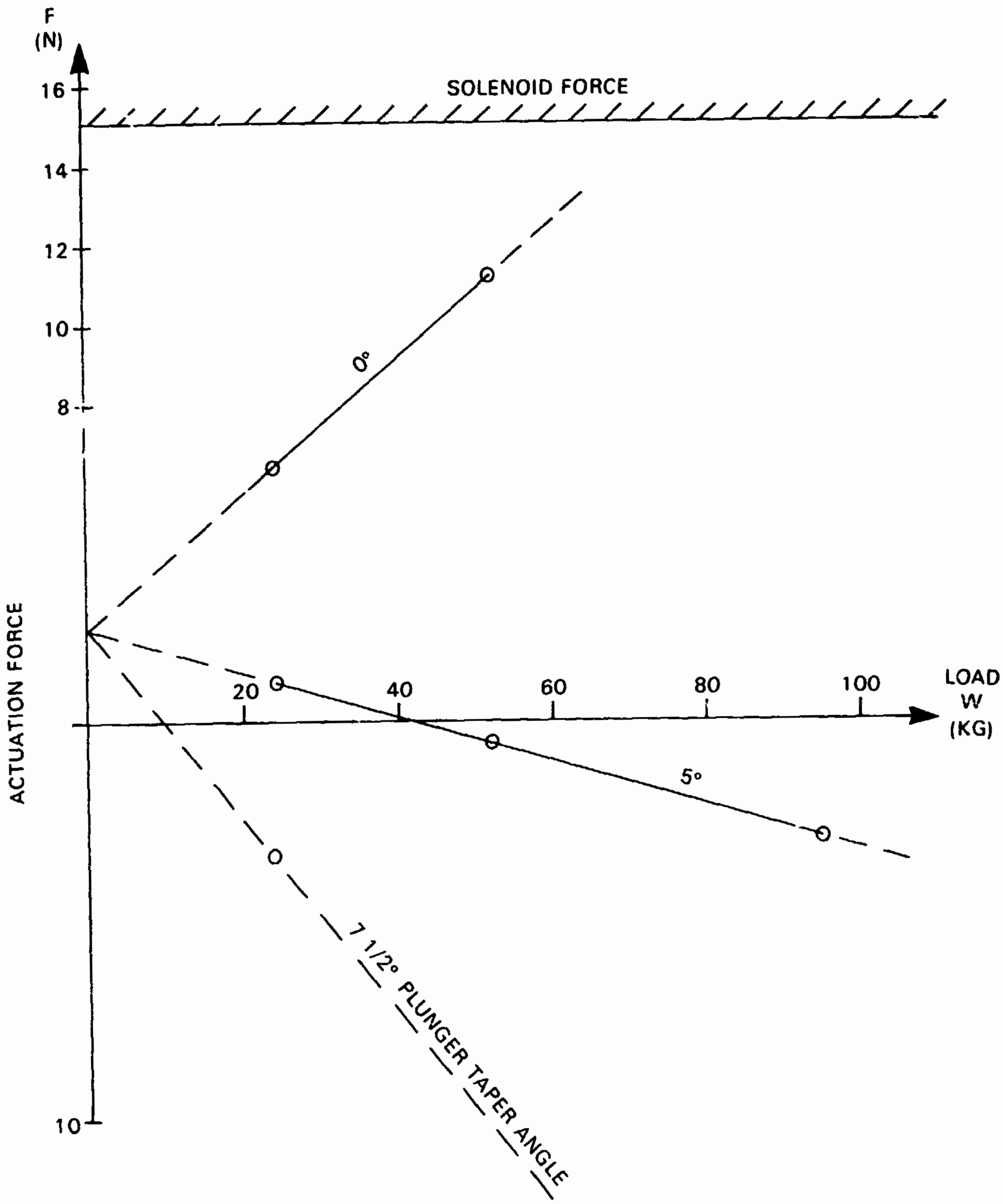

Figure 5. Test Performance of Release Mechanism

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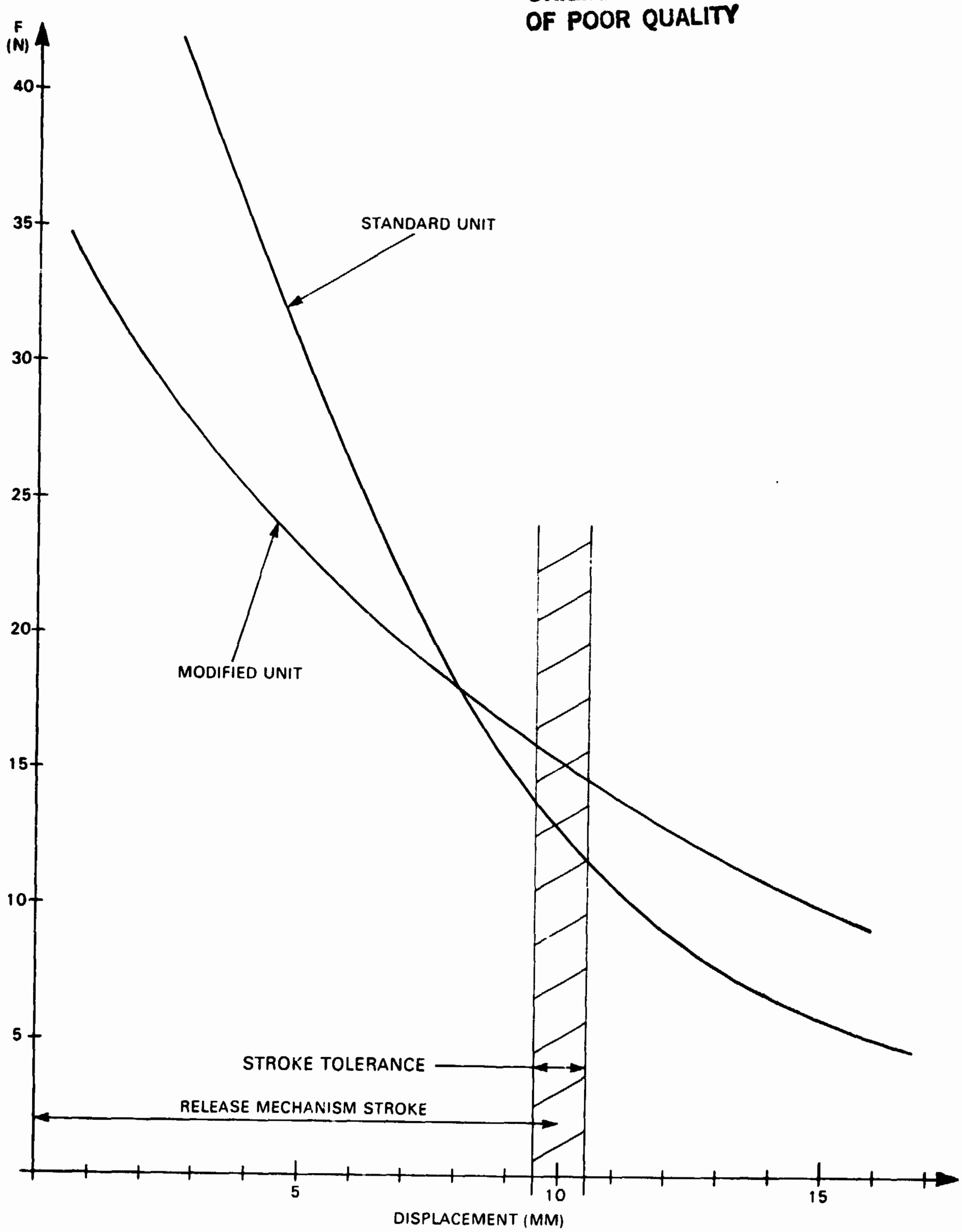

Figure 6. Solenoid Characteristics

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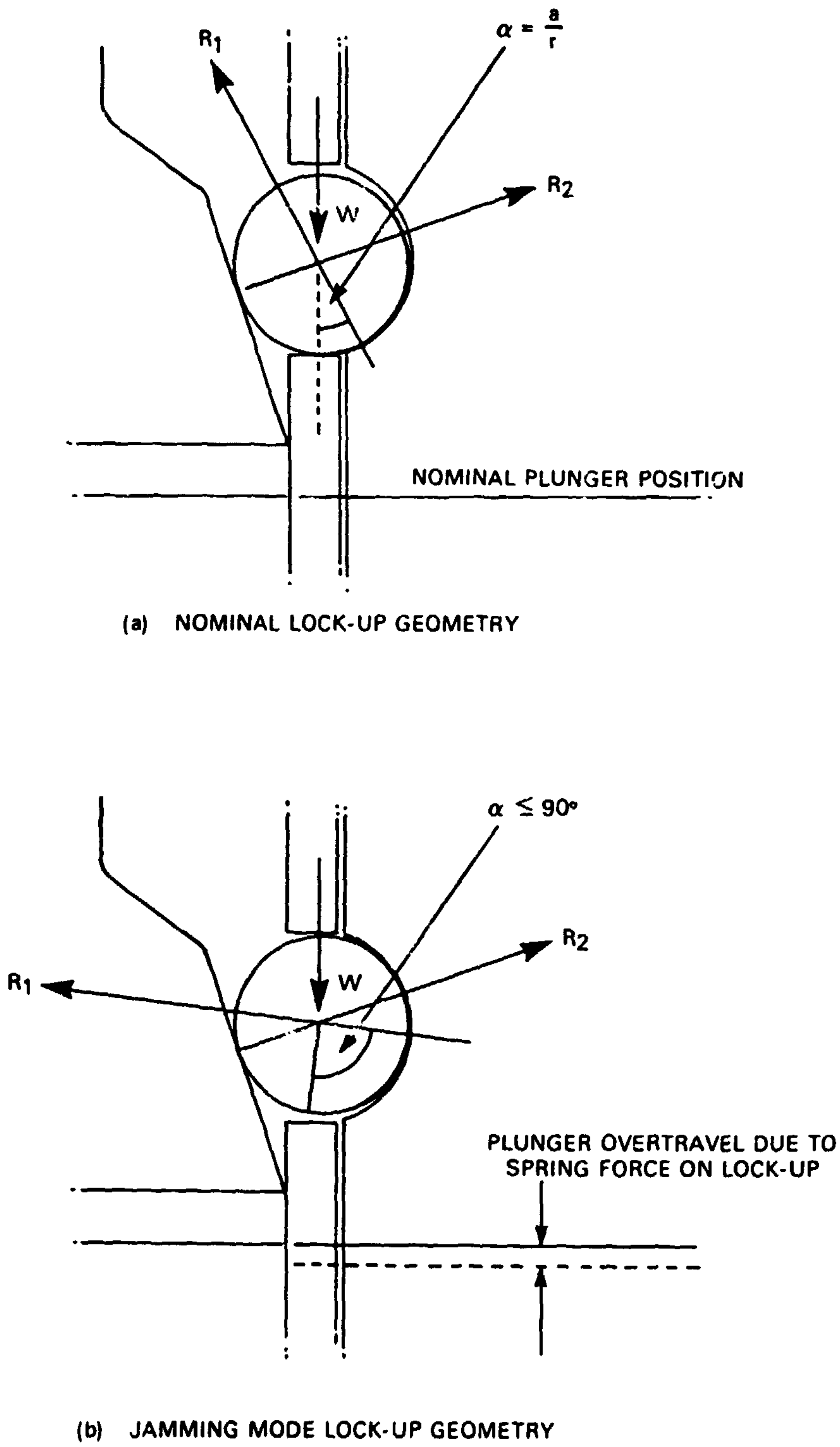

Figure 7. Lock-up Kinematics of Release Mechanism

Because of the spring force and plunger momentum, overtravel of the plunger could force the balls into the back of the groove altering the contact angle for the reaction force R_1.

Because $$R_1 = \frac{W}{\cos \alpha}$$

R_1 becomes very large as α approaches 90°.

When R_1 is very large, two effects cause very large resistance forces on the plunger.

- Side loads on the plunger caused by differential ball reactions become significant and cause high reaction forces at the plunger journals

- The reaction force on the plunger, R_2 becomes large enough to cause rapid lubricant wear allowing sticking of the balls to the plunger

These effects were eliminated by installing a limit stop for the plunger which prevented it from reaching the overtravel condition

Retention Characteristics

Figure 5 shows that the plunger tends to release by itself at higher loads and that a retaining force is required. Several iterations were required to obtain the correct spring force (if too large a force was used, the solenoid could not release). If a minimum spring force was used, uncommanded release could occur when the mechanism was shaken or rotated under full load. When the release performance problems previously described were solved, it was found that a stronger spring could be used and the retention performance was improved correspondingly. Continued rotation of the mechanism with respect to the groove, however, eventually caused uncommanded release because the motion of the balls allowed slip of the plunger. This was not considered a serious problem for this application.

Lubrication Life

The active parts of the mechanism are made from hardened corrosion-resistant steel. Dry lubricants based on molybdenum disulphide are used to prevent galling and to avoid the problems of wet lubricants in an unsealed mechanism,(e.g., contamination risk when mechanism is separated). The plunger is coated with a solid film lubricant per MIL-L-46010 to provide low friction and relatively high contact stress capacity when sliding against the balls. A high rate of wear of this lubricant was observed during initial testing.

When the release performance problems were eliminated as previously mentioned, a considerable improvement in the plunger lubricant life was obtained because the contact stresses of the balls on the plunger had been reduced.

A further improvement that was obtained by adding to the experiment procedure involved rotating the plunger about its centerline occasionally so that the new lubricant was contacted by the balls.

TESTING

Performance Testing

Initially, a simple pass/fail test was used, based on completion of a large number or releases without jamming at normal voltage (i.e., worst-case specification values). To allow the timely detection of problems, however, a characterization test was adopted to determine the performance margins of the release mechanism.

Two methods of defining release performance were used:

- Testing at reduced voltage
- Measuring release delay

The relationship between supply voltage and release force is illustrated in Figure 8. If the voltage is reduced until consistent release no longer occurs, the resistive forces in the mechanism can be determined. If these are significantly higher than predicted a potential problem in the mechanism exists.

Measurements of release delay can be made using an accelerometer mounted on the solenoid housing or by recording the solenoid current profile which dips when the plunger moves. Both have been used and provide an accurate indication of the time between switching voltage to the solenoid and motion of the release mechanism. Both the average value and the consistency of the delay provide a good indication of the health of the mechanism.

Environmental Tests

The following environmental tests were performed by NASA, Johnson Space Center and the Massachusetts Institute of Technology, Laboratory for Space Experiments:

- Electromagnetic compatibility (EMC)
- Vibration of stowed release mechanism
- Thermal cycling
- Toxicity and outgassing

Life Test

A Life Test of one release mechanism was performed and an operating life factor of 4 was demonstrated in relation to mission, ground testing, and crew training operations. At the end of this test the unit was still operating normally.

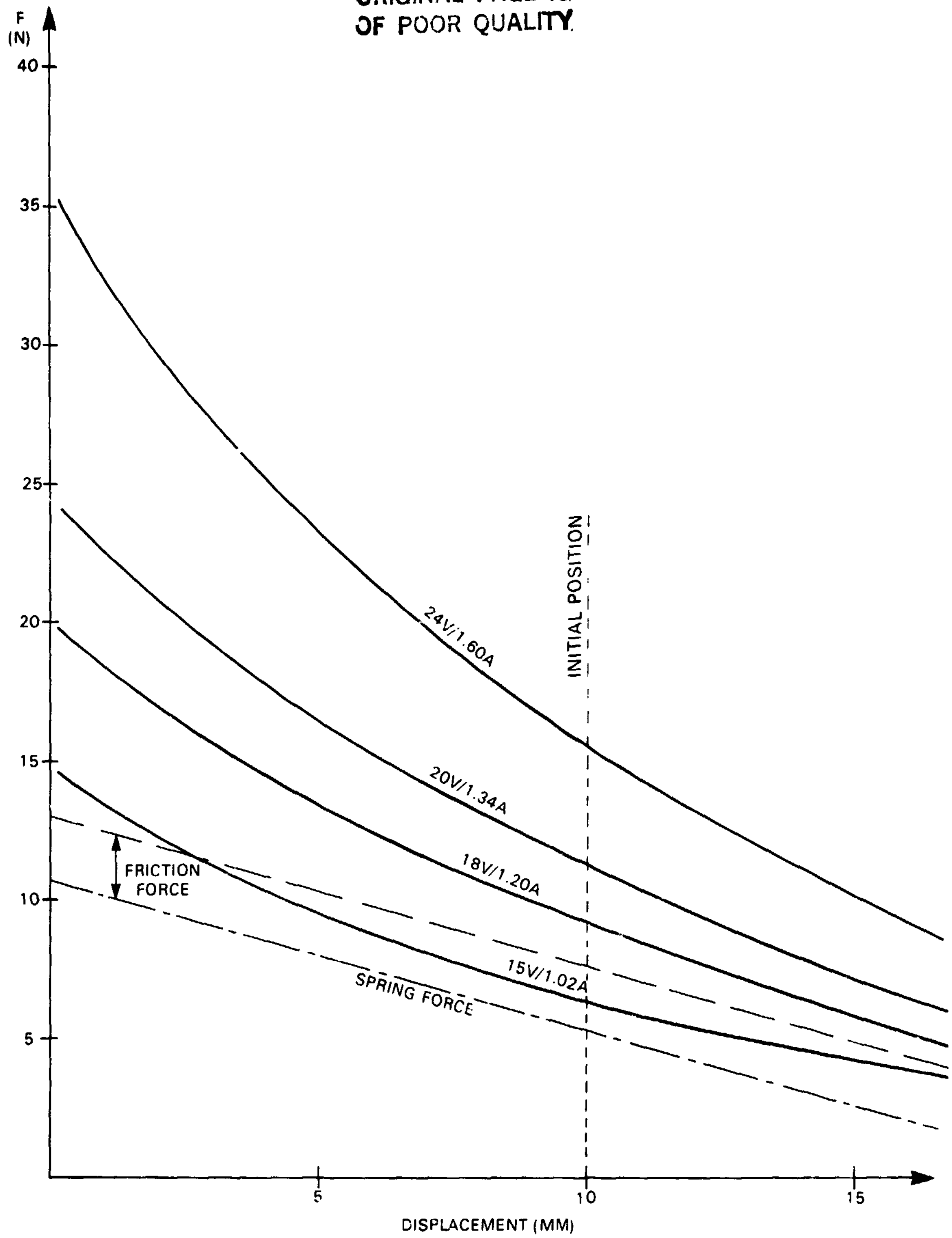

Figure 8. Solenoid Force at Various Supply Voltages

CONCLUSIONS

Three flight units have been delivered for use in Life Science Experiments on the Spacelab 1, D1, and 4 missions.

The unit used on Spacelab 1 (STS-9), which flew in November and December 1983, performed satisfactorily.

The Spacelab D1 and 4 missions are due in June 1985 (STS-26) and December 1985 (STS-32).

The mechanism described in this paper is suitable for other applications requiring quick release under load, with release delay independent of load and supply voltage, low-power consumption, and immediate reusability.

ACKNOWLEDGEMENT

The work described in this paper was performed under contract to the Defence and Civil Institute of Environmental Medicine (DCIEM), Downsview, Ontario, Canada. The authors would like to thank Dr. K.E. Money of DCIEM for his valuable support.